Unit 2

Part 1

Bioenergetics

AP Biology

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Ordered Systems

- Organisms are very **ordered**
- Requires **energy** to maintain
- Why?

1st Law of Thermodynamics

- Energy cannot be made or destroyed, only **transformed or transferred**

Food → Muscle Contraction

(Chemical Energy) → (Mechanical Energy)

Sunlight + CO_2 → Sugars

(Radiant Energy) → (Chemical Energy)

1st Law of Thermodynamics

- The energy being transferred around within matter is called ENTHALPY (H)
- This is not the only consideration for energy available to organisms!
- Maintaining order requires energy!

2nd Law of Thermodynamics

- All matter tends to become disordered
  - Called ENTROPY (S)
    - Ice melts
    - Cells break down
    - Buildings degrade

Putting it all together

$$\Delta G = \Delta H - T\Delta S$$

The *changes* of **energy transfers**, **temperature** of the systems and *changes* in **entropy** affect how much **free energy** we have available to perform biological work.

If G is positive, the process requires energy ☹

If G is negative, the process gives off energy ☺

Authentic Example

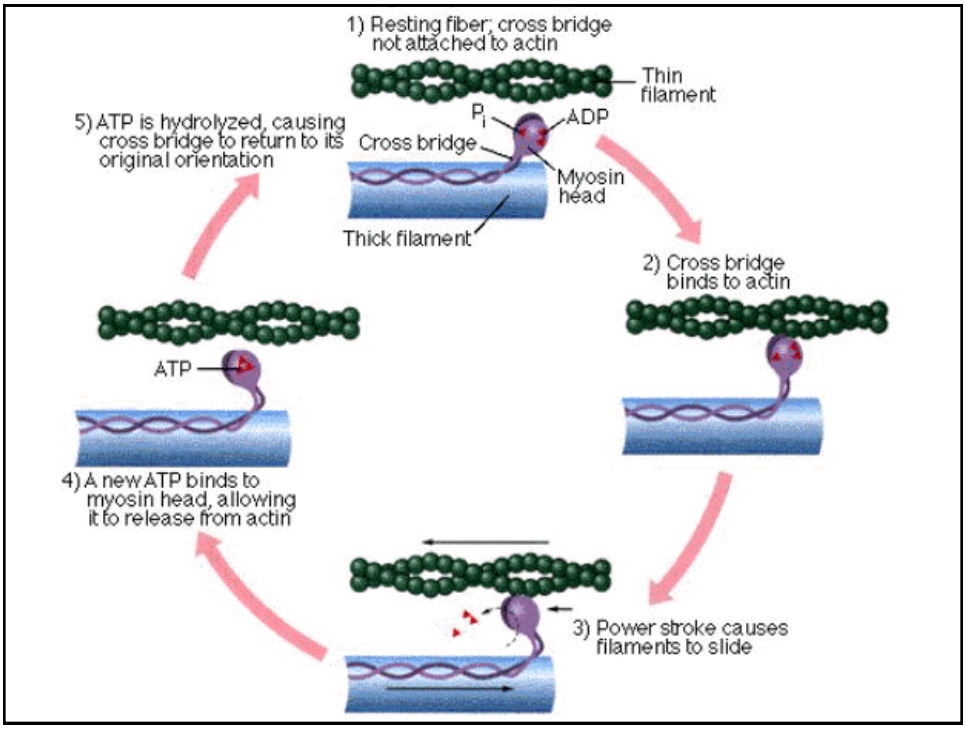
- $\Delta G = \Delta H - T\Delta S$
- Chocolate Cake Enthalpy= 500 calories (H)
- Cell temperature = 20 ^{o}C
- Entropy = 5 cal/c (S)

- Chocolate cake metabolized to individual sugars = 700 calories (H)
- Entropy after metabolizing cake = 10 cal/c (S)

- Solved: Free energy change = - 100
- Increase in entropy but because excess energy is released, it can be used to do work for another reaction.

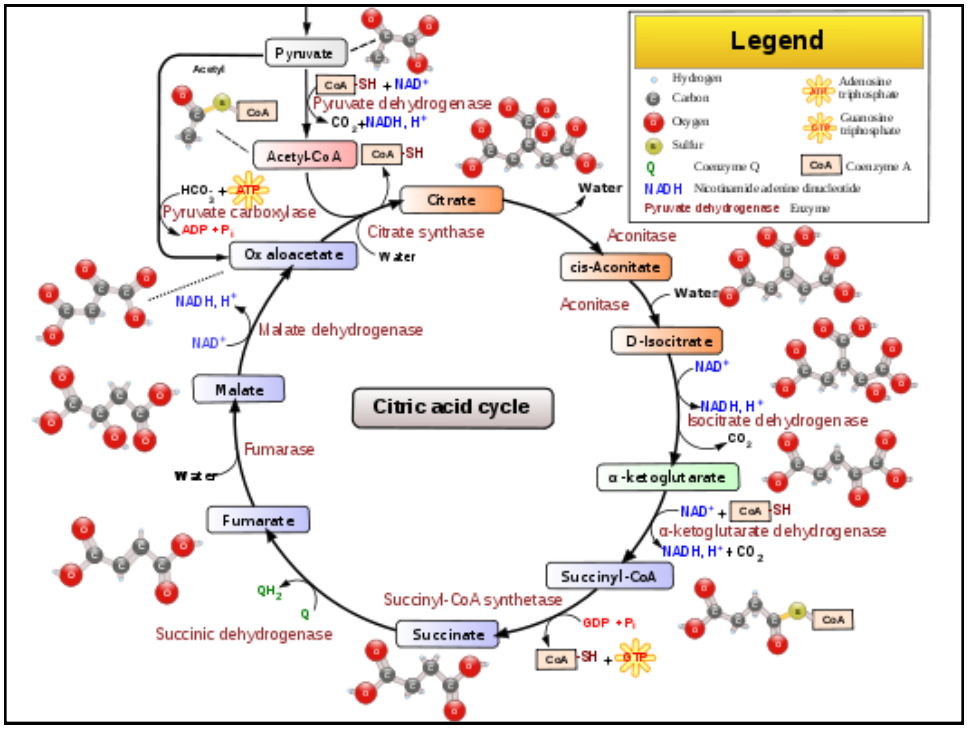
Energy Coupling

- Growth/Work requires a lot of free energy
- By breaking down organic compounds, we increase entropy (disorder).
- The energy released from this can be coupled to a reaction needing energy.



Reactions are Sequential

- To maximize this energy coupling, most biochemical reactions are in steps.
- Molecules can enter at different steps.



Take Home Point

- Living things constantly require free energy to fight the effects of entropy.
- Lack of free energy = DEATH ☹
- Excess free energy = GROWTH ☺

Using Free Energy

- Organisms use free energy to:
  - Maintain organization
  - Maintain homeostasis
  - Grow
  - Reproduce

Temperature Regulation

- Palm tree flowers produce heat in response to fluctuating temperatures.
- Aids in reproduction also…how?
- Low SA:V ratio keeps heat in longer…how?

Temperature Regulation

- Ectothermy:

  The use of external thermal energy to help regulate body temperature.
  - Reptiles

Temperature Regulation

- Endothermy:

  The use of thermal energy generated by metabolism to maintain body temperature.
  - Mammals
  - Birds

Offspring are Expensive!

- I don't mean paying for diapers & tuition…
- Reproducing and rearing of offspring requires significant energy.
- Organisms employ a variety of methods to offset these demands.
  - Seasonal reproduction when nutrients are abundant
  - Biennial Plants

Metabolism & Size

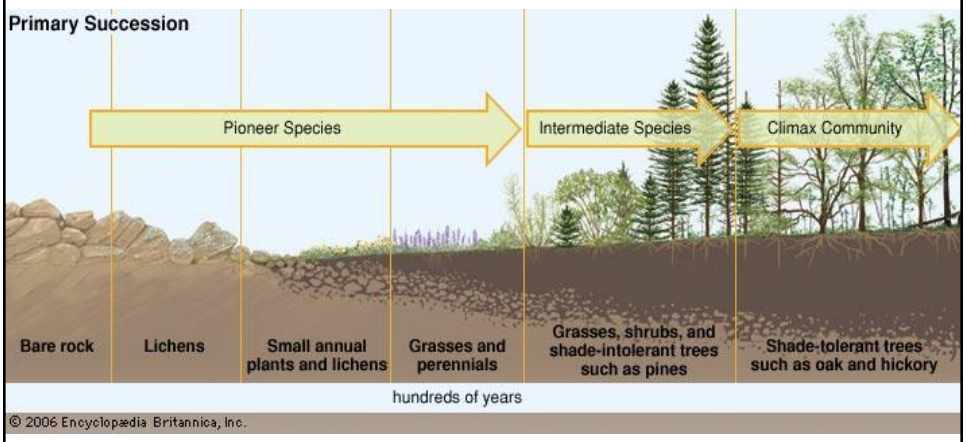
- Also considered is the size factor…
- Small animals have higher MR's
  - Must eat more frequently
- Large animals have lower MR's
  - Can eat less frequently
- …Why? Remember the Palm tree example!

Energy Availability

- Variations in nutrient acquisition strategies produce a variety of organisms.
- Nutritional specialists can be severely affected if their environment is altered.

Energy Availability

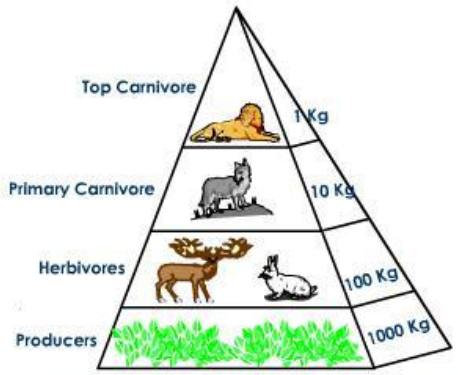
- Effects of sunlight limitations for producers



Energy Availability

- Higher trophic levels are affected by lower trophic levels.

If the number of producers Was reduced by half, what will happen to the higher levels and why?



Upright Pyramid of biomass in a Terrestrial Ecosystem

Capturing Free Energy

- 2 Basic methods:
  1. **Autotrophs**: Use energy from physical sources in environment
     - Sunlight for **photosynthesis**
     - Inorganic molecules (H_2S, NH_3, Fe) **Chemosynthesis**
     - **PRODUCERS**
  2. **Heterotrophs**: Use energy present in carbon compounds present in other organisms.
     - Carbohydrates - Lipids - Proteins
     - **CONSUMERS**

Metabolism Overview

- **Photosynthesis**

Plants, Cyanobacteria, Algae: Produce organics

- **Fermentation**

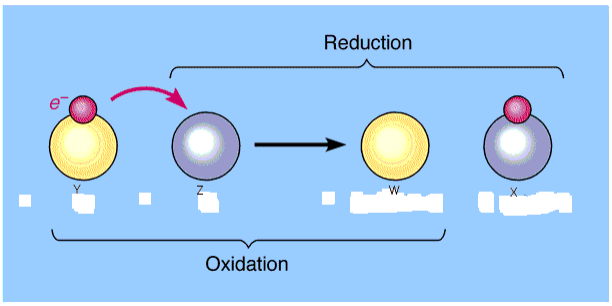
Many eukaryotes & prokaryotes, ANAEROBIC: Break down organics

- **Cellular Respiration**

Many eukaryotes & prokaryotes, AEROBIC or ANAEROBIC: Break down organics

Electrons are the Energy Currency

- Gaining electrons energizes
  - Called reduction/being reduced
- Losing electrons lowers energy
  - Called oxidation/being oxidized

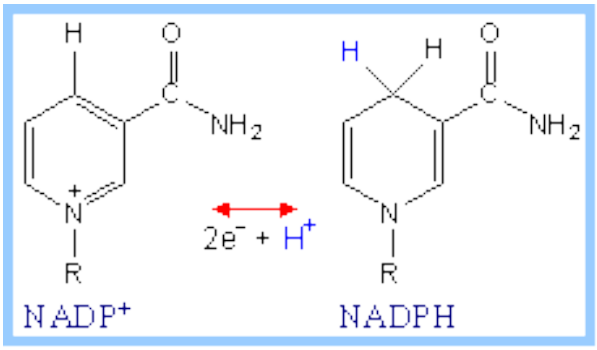


Electrons are Reactive

- Electrons moving around where they shouldn't is BAD.
- Results in compounds changing to unwanted unstable forms.
- Special molecules called **electron carriers** serve to move electrons around where they are supposed to go.
- Special molecules called **electron acceptors** serve as the final "resting place" for electrons.

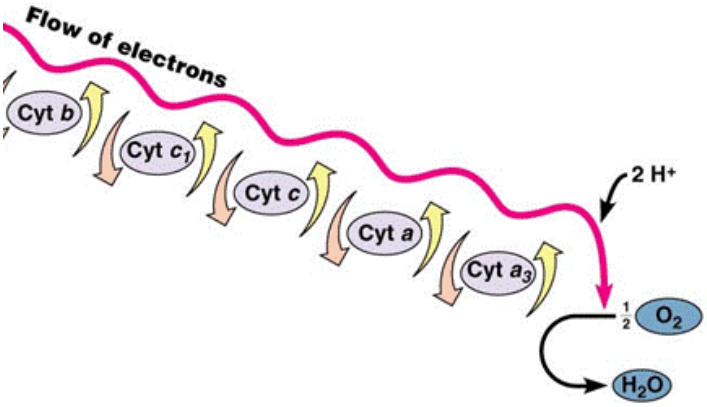
Electron Acceptors

- Photosynthesis uses $NADP^+$
- This is also the electron carrier.



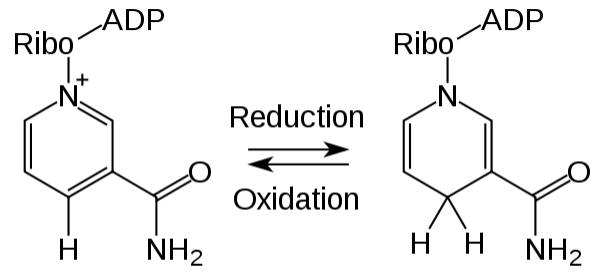
Electron Acceptors

- Aerobic Cellular Respiration uses O_2



Electron Carriers

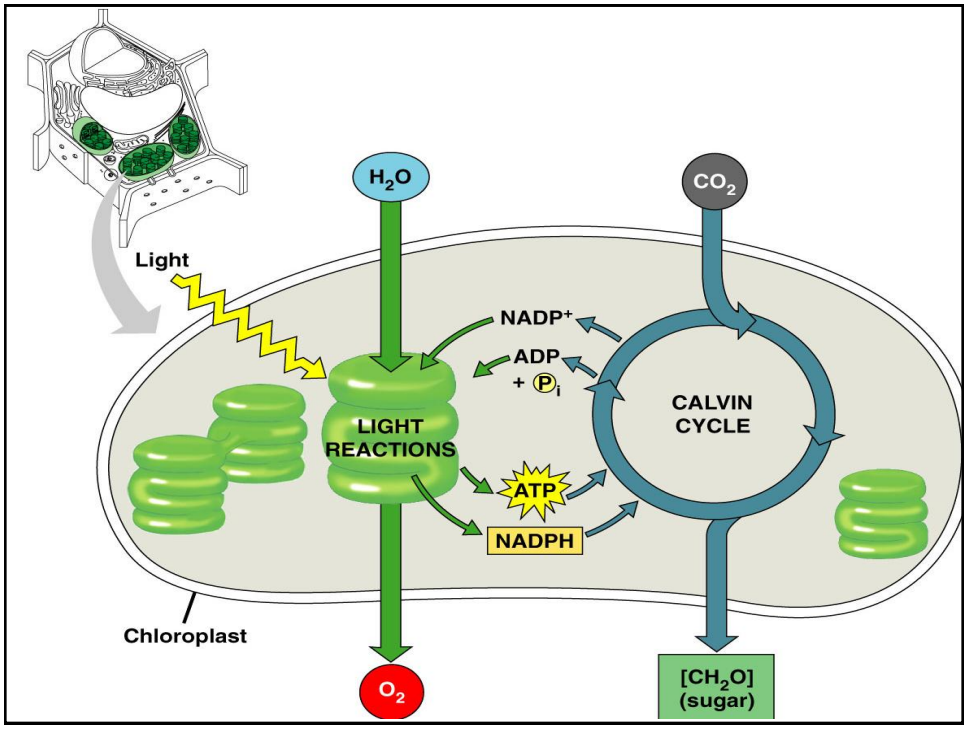
- Cellular Respiration & Fermentation use NAD+



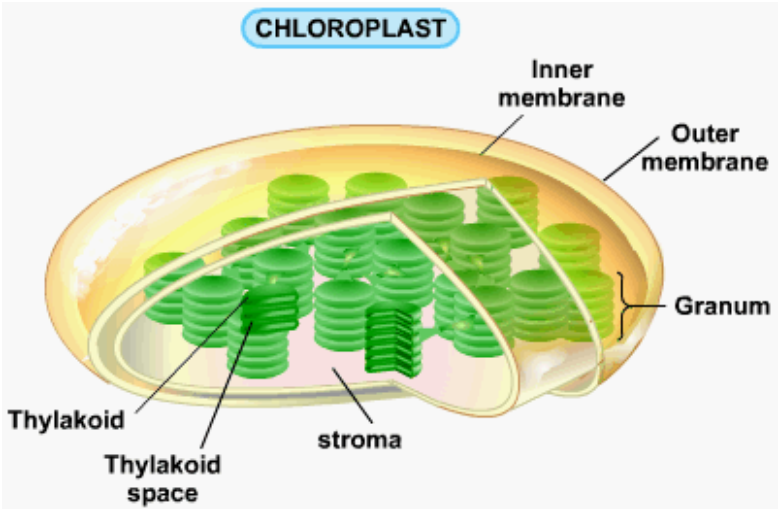
$NAD^+ + H^+ + 2e^- \longrightarrow NADH$

Photosynthesis

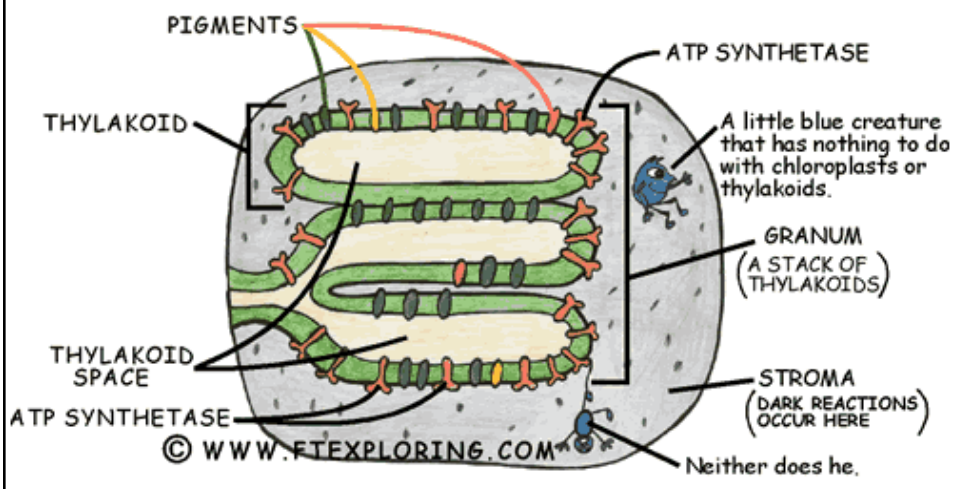
- Summary:
  - A series of coordinated reactions in Eukaryotes that captures free energy from sunlight to produce ATP & NADPH, which power the production of organic molecules. Prokaryotes use a similar pathway but ***not in chloroplasts.***
  - 2 Phases:
    - The Light-Dependent Reactions (Energy Capture)
    - The Calvin Cycle (Organic Molecule Production)



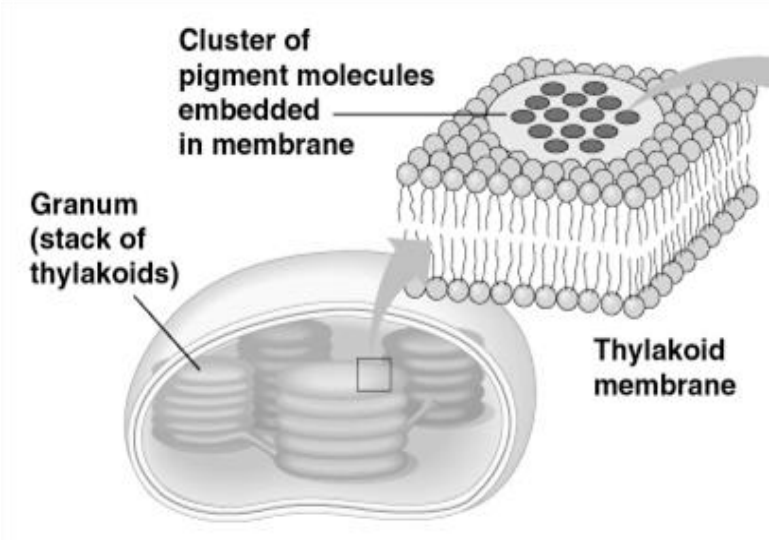
Chloroplast Structure



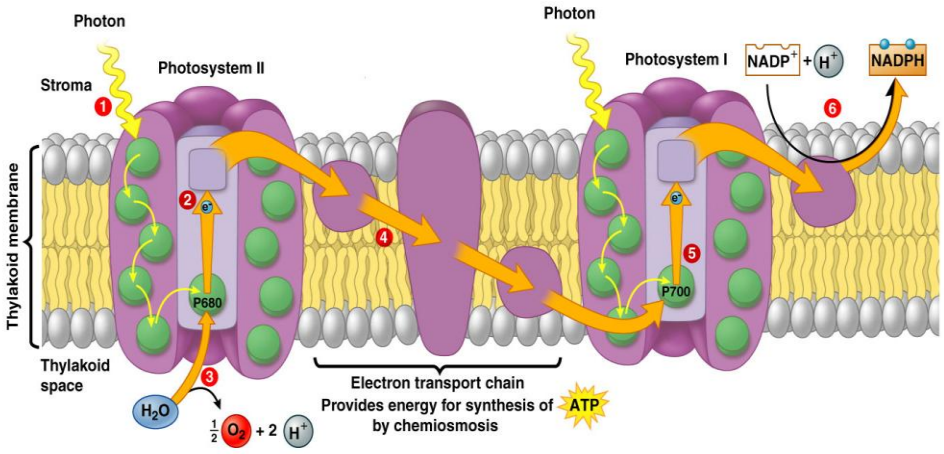
Thylakoid Structure



Photosystems Contain Chlorophyll Pigments

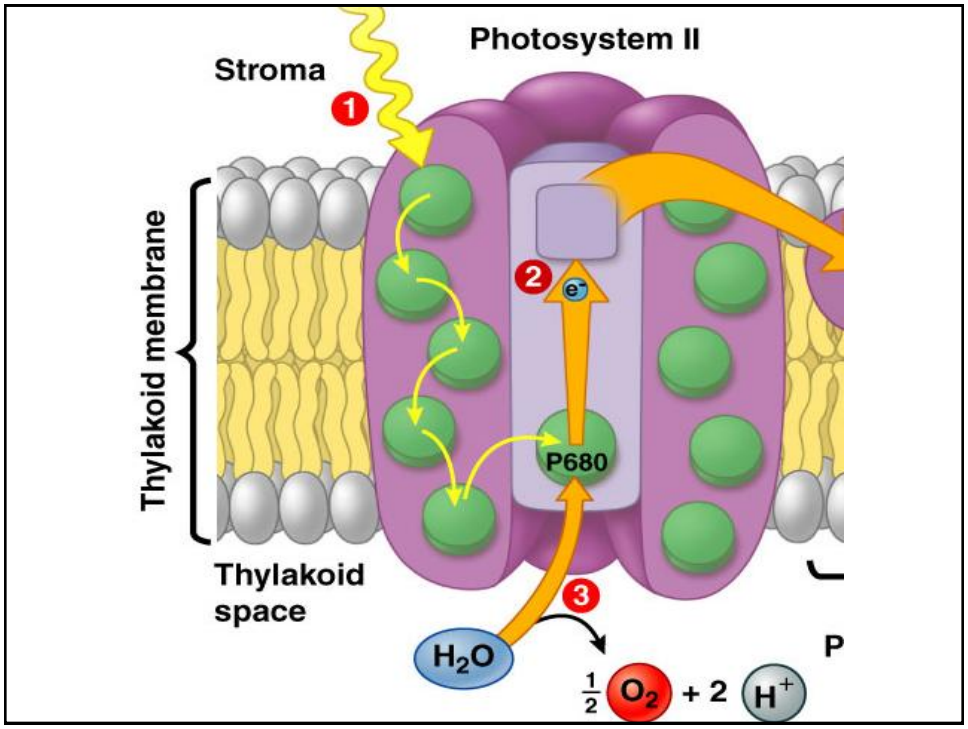


Part 1: The Light Reactions Occur in the thylakoids



Reactions

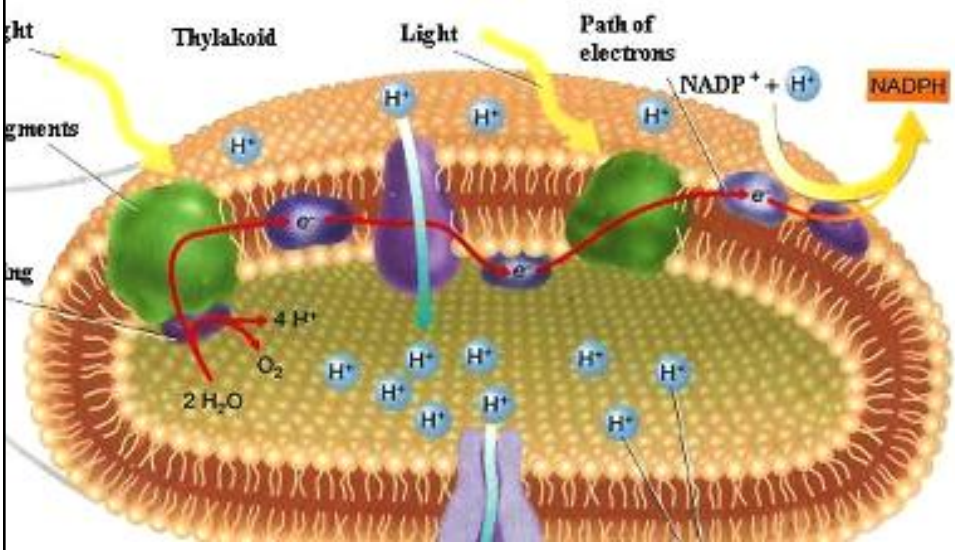
- **Light** energizes electrons in PS2 and causes them to 'jump' from PS2 reaction center to a primary electron acceptor.
- **Water** is split into **2 Hydrogen** and 1 **Oxygen**. The 2 electrons involved in holding water together are transferred to PS2… replacing its 2 lost electrons.



Reactions

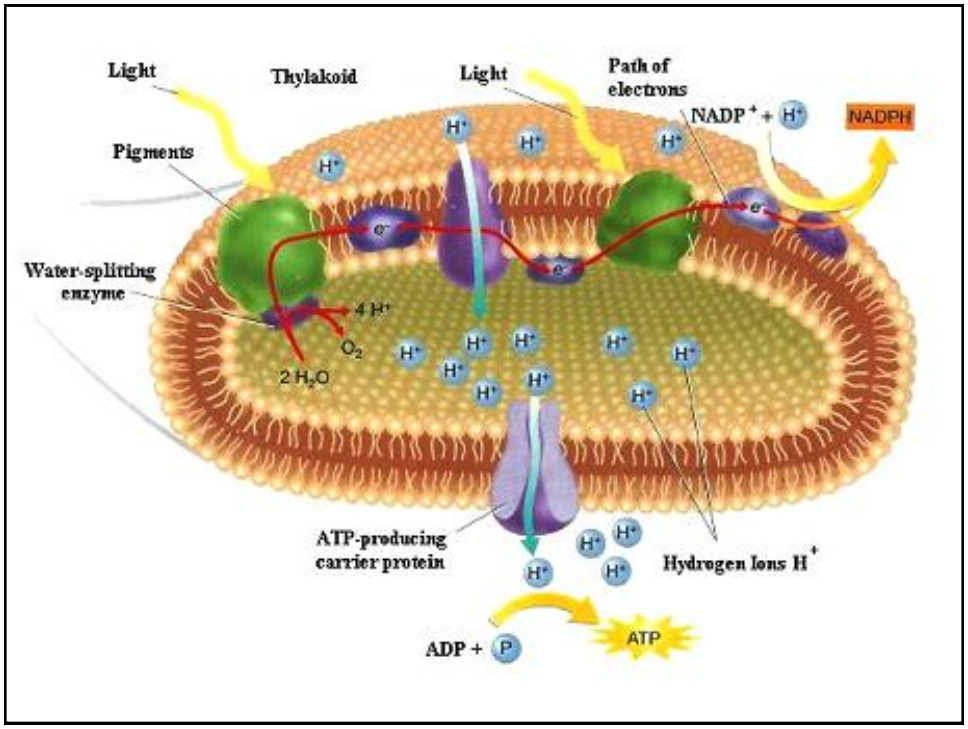
- The original 2 electrons begin to pass through an **Electron Transport Chain (ETC-1).** The "falling" of electrons releases energy that can be used to do work. The "work" is stockpiling hydrogen ions inside the thylakoid space… creating an **electrochemical gradient.**
- The hydrogen ions stocked inside the thylakoid space are "dying" to get out! They are IONS so they cannot leave just anywhere… can only leave through a specific place.

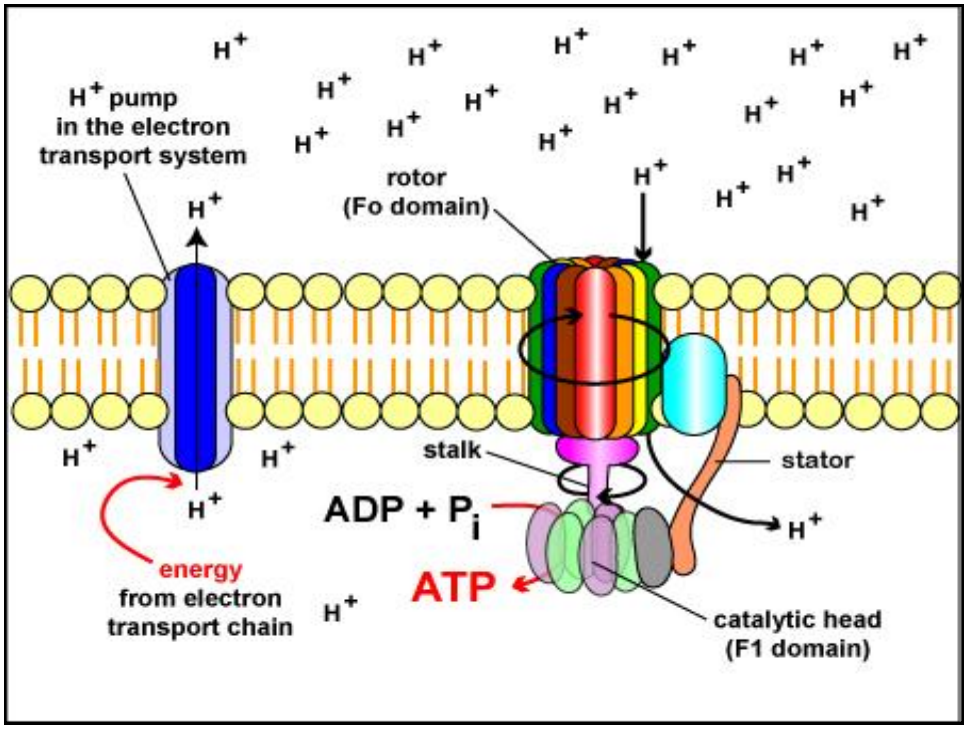
Electrochemical Gradient



Reactions

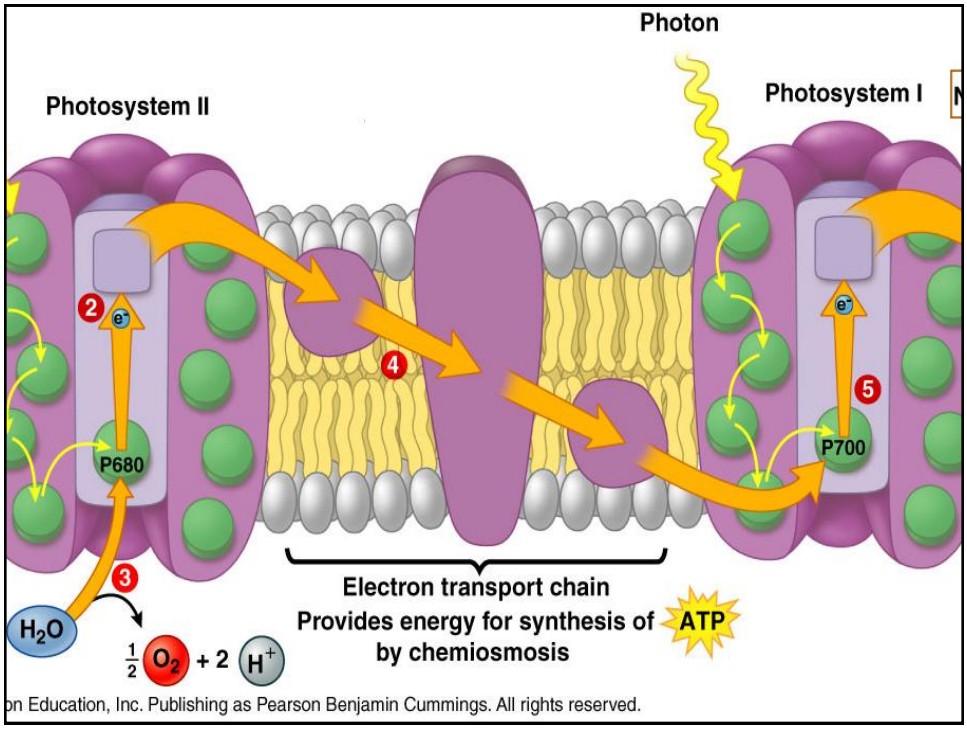
- The place is through an enzyme channel called **ATP SYNTHASE**. When hydrogen ions pass through, ATP Synthase is energized and links ADP with an extra P = ATP.
- This method of creating ATP is called **PHOTOPHOSPHORYLATION**.
- The energy released from H+ moving through ATP synthase is called **CHEMIOSMOSIS.**


Light
Thylakoid
Light
Path of electrons
NADP+ + H+
NADPH
Pigments
Water-splitting enzyme
4 H+
O2
2 H2O
ATP-producing carrier protein
Hydrogen Ions H+
ADP + P
ATP


H+ pump in the electron transport system
rotor (Fo domain)
stalk
stator
ADP + Pi
ATP
energy from electron transport chain
catalytic head (F1 domain)

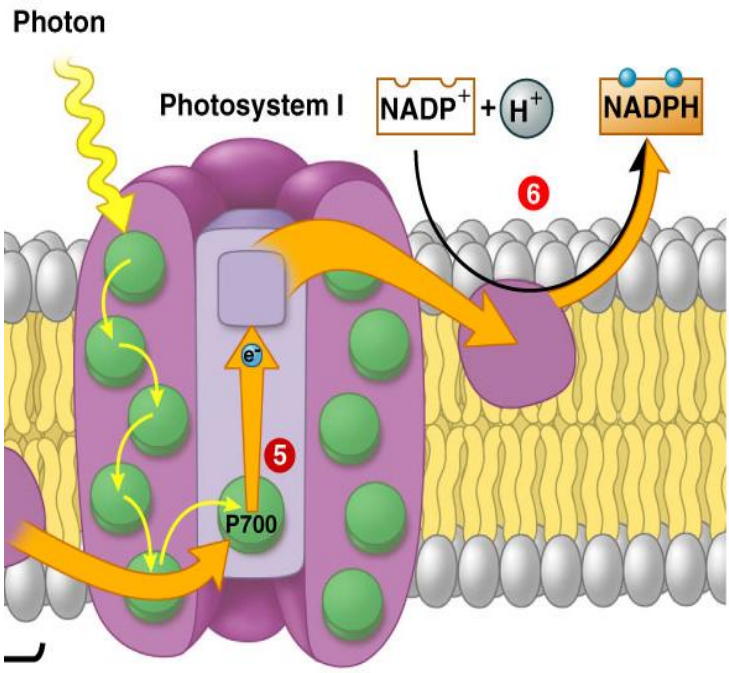
Reactions

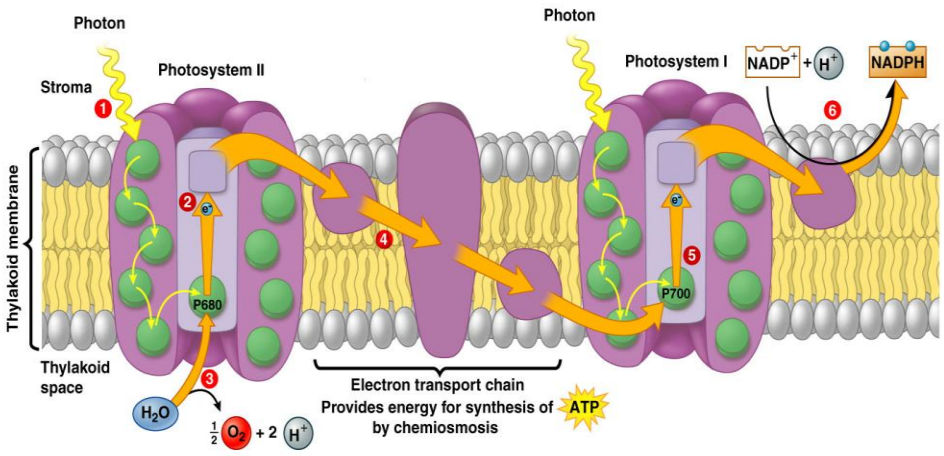
- Meanwhile, back in ETC-1… the ORIGINAL electrons are still "falling". They finally reach ANOTHER photosystem called **PS1.** At this point, PS1 has lost electrons the same way as PS2 did in step 1 (light energizes them and they head off into ETC-2).



Reactions

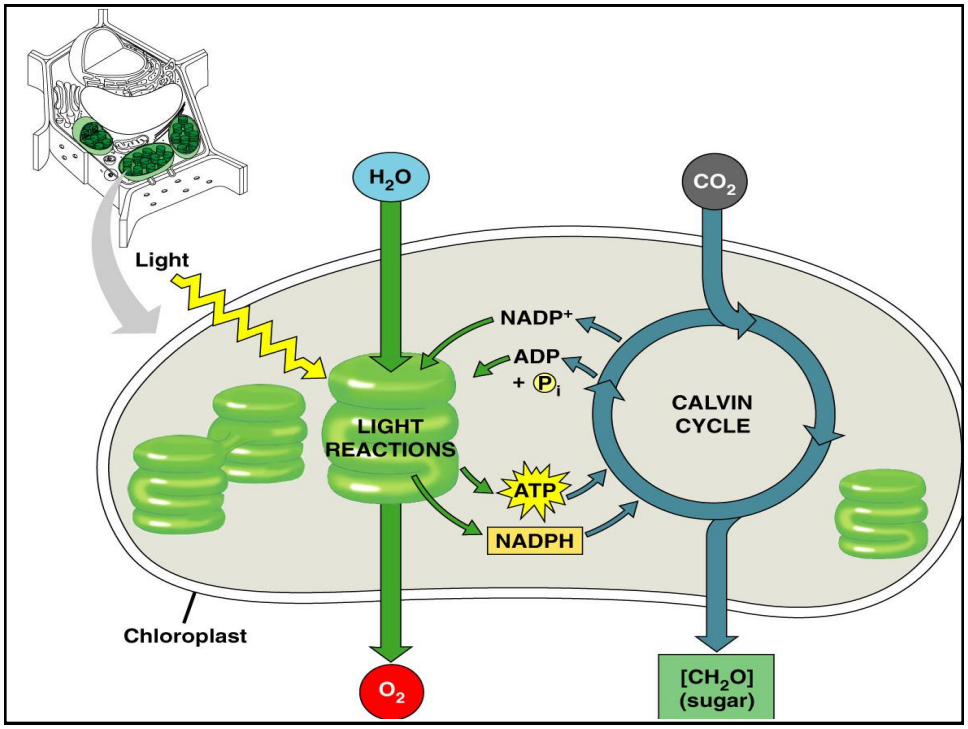
- These “new” electrons from PSI are now “falling” down ETC-2 until they reach their final destination…NADP+
- NADP+ accepts these electrons but now it needs an extra atom to be attached to.
- The extra atom is HYDROGEN. NADP+, electrons, and hydrogen = NADPH.
- NADPH will carry the electrons to where they will be used next = The Calvin Cycle





Part 2: The Calvin Cycle

- The Calvin Cycle uses ATP & NADPH produced during the light reactions to produce carbohydrates from Carbon Dioxide (CO_2)
- This occurs in the STROMA of the chloroplast

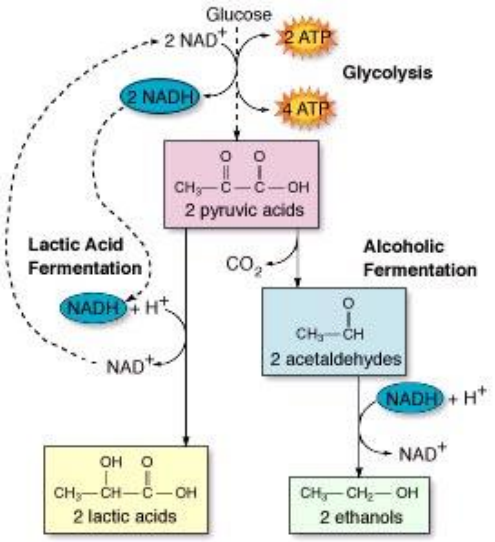


Photosynthesis & Evolution

- Oxygen production during photosynthesis evolved on earth around 3.5 billion years ago in **prokaryotes**.
- Oxygen was a **toxic** waste product of this reaction.
- As a consequence, it was released into the atmosphere as a means of detoxification.
- This contributed to the conversion of Earth's atmosphere **from anaerobic to aerobic**, triggering the "oxygen catastrophe".
- As a result, aerobic metabolism evolved to utilize the oxygen that was released by photosynthetic organisms.
- Anaerobic organisms either died out or fled to anaerobic environments.

Anaerobic Processes

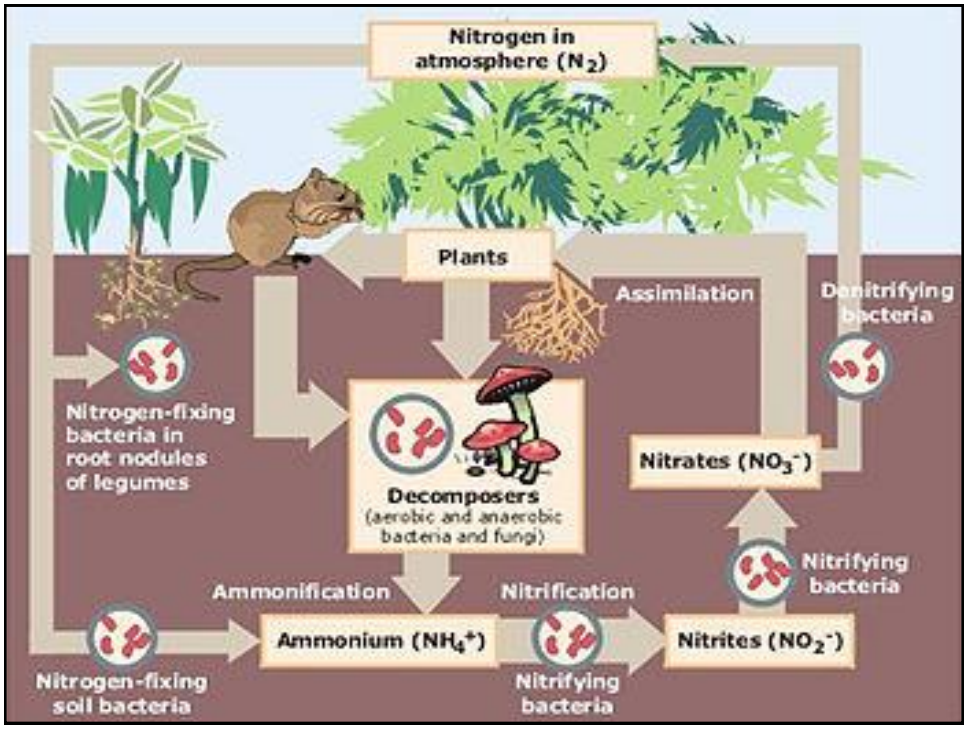
- Fermentation
- Notice **no oxygen** in the reactions
- Produces organic compounds as byproducts:
  - Ethanol: Plants
  - Lactic Acid: Muscles



Anaerobic Processes

- Anaerobic Respiration
- Notice **no oxygen** in the reactions
- Denitrifying Bacteria in Soil

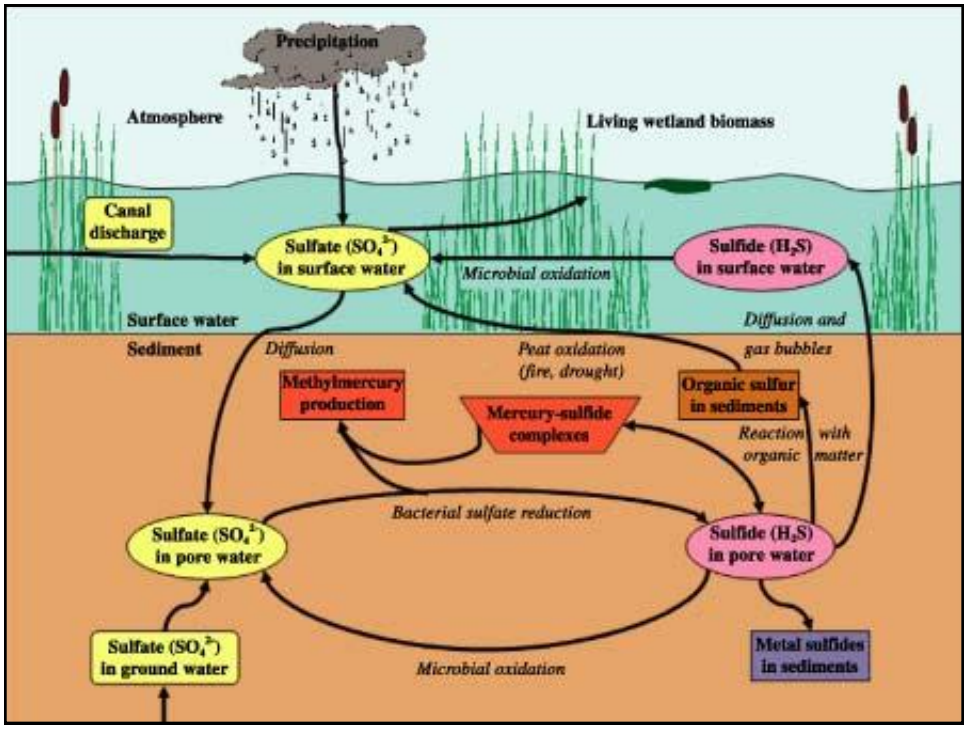
$$C_6H_{12}O_6 + 4NO_3 \rightarrow 6CO_2 + 6H_2O + 2N_2$$



Anaerobic Processes

- Anaerobic Respiration
- Notice **<u>no oxygen</u>** in the reactions
- Sulfur Reducing Bacteria in water/soil

$$C_6H_{12}O_6 + SO_4^{2-} \rightarrow 6CO_2 + H_2S + H_2O$$

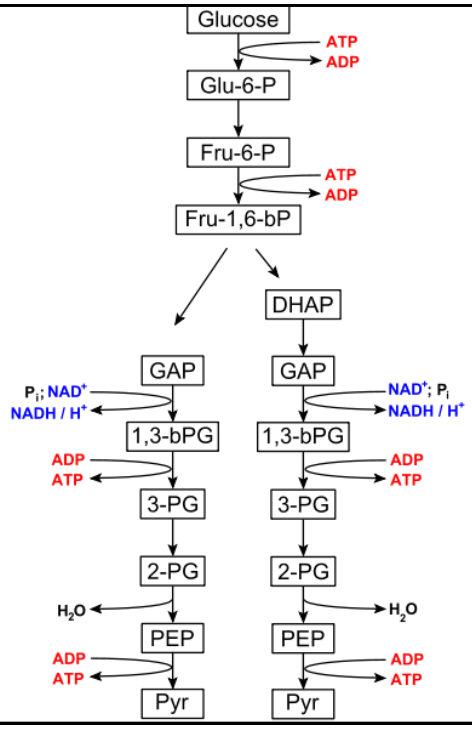


Aerobic Cellular Respiration

- In Eukaryotes, this pathway is a series of enzyme-mediated steps that harvest the energy stored in simple carbohydrates.
  - Animals (eat then metabolize)
  - Plants (create then metabolize)

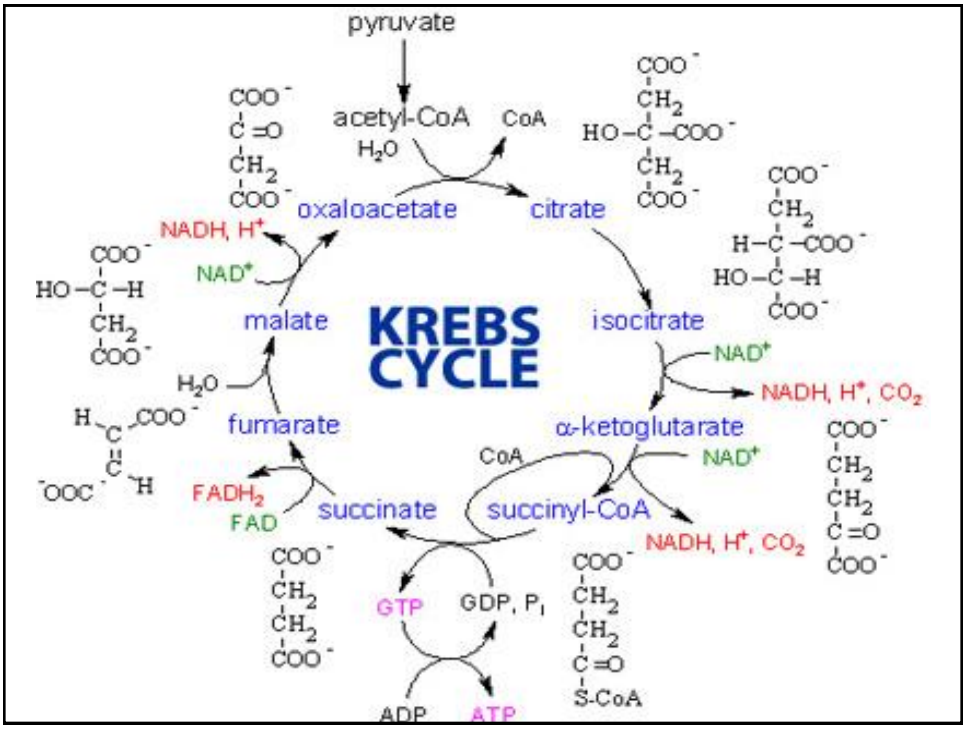
Phases of A.C.R.

- Glycolysis: Rearranges molecules in **glucose** to eventually form a molecule called **pyruvate**. In the process, **ATP** is formed via substrate-level phosphorylation and electrons are captured by NAD+ to form **NADH**.
- Occurs in cell cytoplasm
- Universal pathway…common ancestry!



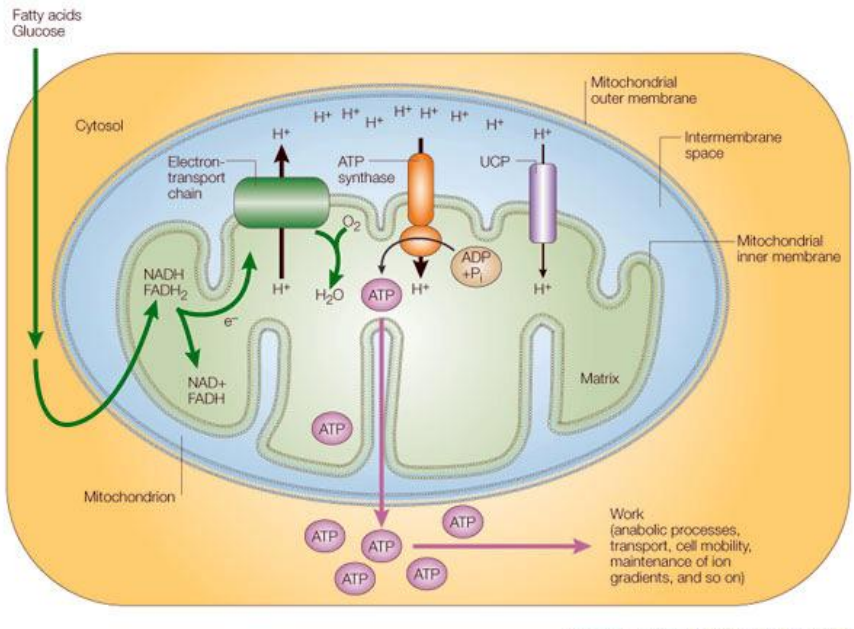
The Krebs Cycle

- Pyruvate is transported into the mitochondion for further oxidation in the Krebs Cycle.
- In the Krebs Cycle, CO_2 is released from organic intermediates, ATP is made via substrate-level phosphorylation, and electrons are captured by NAD+ & FADH to form NADH and $FADH_2$.
- Electrons captured are transferred to an ETC via NADH and $FADH_2$.



Electron Transport Chains

- Previously seen in photosynthesis.
- Located on specialized membranes of mitochondria and chloroplasts in eukaryotes.
- Located on plasma membrane in prokaryotes.

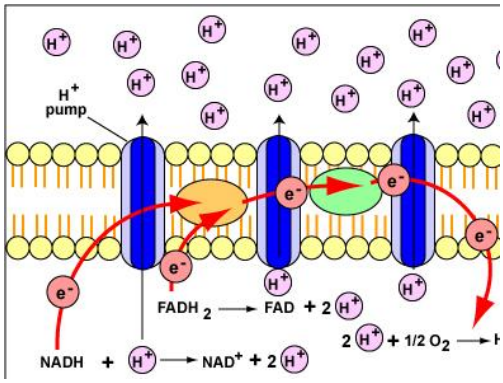


Flow of Electrons

- Electrons delivered by NADH & $FADH_2$ are passed to a series of electron acceptors as they move towards the terminal acceptor, O_2
- What was the terminal acceptor in photosynthesis?

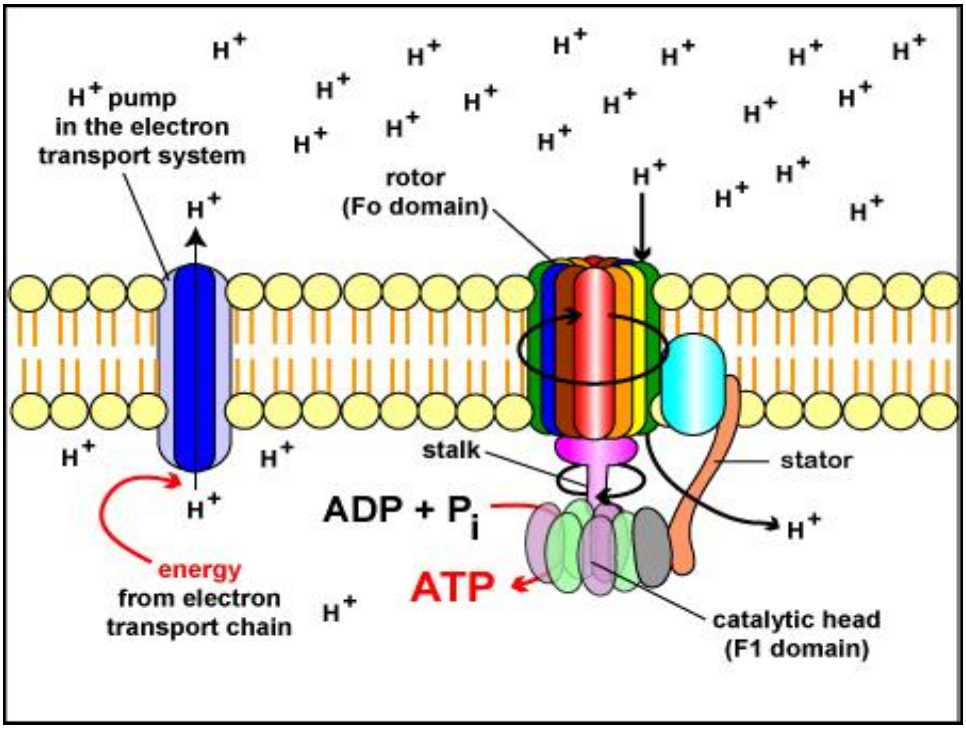
Electrochemical Gradient

- Flow of electrons results in energy to power movement of H+ ions, creating separate regions of high H+ concentrations from regions of low H+ concentrations.



Electrochemical Gradient

- The flow of H+ back through the membrane-bound ATP Synthase by chemiosmosis generates ATP.
- Because the electrons powering all this movement came from oxidizing organic compounds, this ATP forming process is called **OXIDATIVE PHOSPHORYLATION**.
- What was it called in photosynthesis?



The Goal of All This Was???

- To make ATP!
- ATP can now serve as a source of free energy anywhere in the cells.
- Why go through all this trouble to make ATP?
- Why not just couple an energy releasing reaction to any reaction requiring energy?

Thermodynamics!

- ATP is a **renewable & efficient** energy resource used in almost all metabolic pathways.
- Instead of constantly trying to use catabolism to meet the demands of anabolism, cells use catabolism to create ATP.
- Why is this logical?

Thermodynamics!

- Breaking down 1 molecule of glucose produces about 686 kcal/mol. On average, living & non-living systems conserve a maximum of 25% energy released. This would leave only 171.5 kcal/mol of free energy.
- 1 glucose can also be used to make about 38 ATP during cellular respiration. 1 ATP produces about 7kcal/mol that can be **directly** used. This would provide 266 kcal/mol… **more efficient (39%)**

Practice Free Response

- The endosymbiotic theory proposes that Eukaryotes evolved by means of an ancestral prokaryote engulfing another prokaryote.
- The chloroplasts in eukaryotes are now obligate symbiotes as are mitochondria.

Justify these claims